

# Memory as Behavior: The Importance of Acquisition and Remembering Strategies

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The study of memory has traditionally been the province of cognitive psychology, which has postulated different memory systems that store memory traces to explain remembering. Behavioral psychologists have been unsuccessful at empirically identifying the behavior that occurs during remembering because so much of it occurs rapidly and covertly. In addition, behavior analysts have generally been disinterested in studying transient phenomena such as memory. As a result, the cognitive interpretation has been the only one that has made and tested useful predictions. Recent experimental evidence acquired while having participants "think aloud" suggests that a behavioral approach to memory may provide a superior account of memory performance and allow applied scientists to observe and modify memory-related behavior with well-known applied behavior-analytic techniques. We review evidence supporting and extending the interpretation of memory provided by Palmer (1991), who described memory in terms of precurent behavior that occurs at the time of acquisition in preparation for problem solving that occurs at the time of remembering.

Cognitive psychologists and behaviorists have traditionally been at odds over the issue of memory, with cognitive psychologists claiming that memory is central to understanding human behavior (e.g., Bjork & Bjork, 1996) and behaviorists arguing that it is a theoretically incoherent notion that does not warrant separate study (e.g., Branch, 1977; Donahoe & Palmer, 1994; Palmer, 1991; Skinner, 1977). In our opinion, the source of the disagreements is the different approach to the study of human behavior advocated by the two camps. Behaviorists carefully specify the contingencies that govern the acquisition of particular behaviors, but cognitive psychologists are typically interested in studying the limits of the human system's

abilities. Cognitive psychologists generally believe that the study of memory has produced some central, defining limits on human performance that inhibit our ability to acquire particular repertoires under conditions of sufficient reinforcement, just as a rat lacks the capability of producing meaningful speech.

There is no inherent problem with such a view from a behavioral perspective. For behaviorists this could represent the study of the characteristics of stimulus control and the behavioral processes associated with the loss of stimulus control. What is generally problematic is the introduction of explanatory fictions like *short-term memory* as theoretical primitives to supposedly explain the regularities (for examples of this type of argument in the domain of memory, see Branch, 1977; Watkins, 1990). Therefore, we see no problem with drawing upon the empirical results of cognitive research, as opposed to the theoretical explanations thereof, in our review. Where possible, we will reinterpret memory-related claims so as to make

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them theoretically acceptable to behaviorists, extracting the actual claims and findings from the explanatory fictions (or, as cognitive psychologists prefer, the hypothetical constructs).

Our purpose in writing this paper is to advocate a view of memory based on the work of the behavior analyst Palmer (1991) and the cognitive psychologists Ericsson and Kintsch (1995; Ericsson & Delaney, in press). All of these authors propose, with rather startling concordance given the antagonistic histories of the two fields, that many memory phenomena can be described as being mediated by simple acquisition and remembering strategies that can be described behaviorally, and therefore, we infer, can be modified by appropriate means. It is our view that remembering occurs not, as many cognitive psychologists would have it, because the memory system remembers, but rather because a person engages in particular behaviors both during learning and during recall that enable the person to respond appropriately to particular stimuli at a later time. In demonstrating that such behavior is frequently observed in special populations (e.g., among memory experts), we hope that behaviorists will begin to investigate memory phenomena more carefully and develop methods to improve memory performance in particular domains. We also believe that by emphasizing a behavioral approach, cognitive psychology can benefit by seeing that some of the inherent limits that they suggest are less plausible once the behavior underlying memory performance in particular situations has been specified (Chase & Ericsson, 1981; Ericsson & Delaney, in press; Ericsson & Kintsch, 1995).

Most of the arguments we outline here have been presented in slightly different form by Ericsson and Kintsch (1995) or Ericsson and Delaney (in press). Our role in writing this is more as translators than as theorists; our primary contribution is to make this work, which appears in cognitive publications using cognitive terminology, accessible to behavior analysts by integrating it with Palmer's (1991) interpretation of memory. At the same time, we hope to support Palmer's interpretation with the data gleaned from the cognitive literature. We

will restrict our discussion to humans because the acquisition and remembering strategies we are interested in are directly observable only in humans and not because other animals might not use them.

We will begin by briefly describing traditional cognitive models of memory, starting with Ebbinghaus' (1885/1964) pioneering work on learning and forgetting. Next, we will discuss our proposal for a behavioral interpretation of memory, arguing that performance on some of these tasks could not be explained within the traditional cognitive models. Finally, we will conclude with some speculations about how such mechanisms might be relevant to behavior analysts.

### COGNITIVE ATTEMPTS TO DISCOVER LIMITS BY OBSERVING THE MEMORY TRACE

For more than 1,500 years, philosophers have been vexed by the problem of what memory is and how it works. They reasoned that because events ceased to exist once they were over the event itself was not recalled, but rather some sort of imperfect copy of the event, which is today called the memory trace. The trace itself could not be examined by others; rather, words or pictures would have to be created that conveyed some relevant portion of that memory to others. For example, Saint Augustine wrote in his *Confessions*, "When we relate the past truly, it is not the things themselves that are brought forth from our memory – for these have passed away: but words conceived from the images of the things: for the things stamped their prints upon the mind as they passed through it by way of the senses" (Augustine, 398/1977, p. 353). Hence, learning something was not viewed as a behavior – something the organism does – but rather as something that happened to the organism, as the memory trace was "stamped" on the mind.

The first serious scientific attempt to understand the properties of these memory traces was initiated by Ebbinghaus (1885/1964), who used himself as a subject, rather heroically, for about 6 years of experimentation on memorizing lists. The main problem he faced was in equating the different lists to be learned for difficulty. If the items to be

learned already had existing associations, such as between two words, then they might be easier to learn, and he would be unable to study the formation of the memory trace in its pure form, uncontaminated by the influences of preexisting knowledge. To combat this problem, he chose meaningless consonant-vowel-consonant groupings called nonsense syllables such as VUB and SOQ as his stimuli. A second problem was the possibility of his employing mnemonic behaviors that would create new associations between the items. Such behaviors were viewed as nuisances that had to be eliminated by using a rapid presentation rate. Even early on, though, it became clear that it was not at all easy to eliminate the influence of preexisting associations among items and mnemonic behaviors. For example, Müller and Schumann (1894) found that within lists of nonsense syllables, those that rhymed or began with similar sounds were recalled better.

The idea that memory is mediated by memory traces was bolstered when a derived concept, that of memory capacity, was seemingly verified by Miller (1956) in an entertaining paper called "The Magical Number Seven, Plus or Minus Two." If one believes already that remembering involves the storage of traces, then it makes sense to count the number of such traces that can be

held without forgetting, that is, the memory capacity. Miller's crucial insight was that for many different types of materials and participant populations, there was a remarkable consistency in immediate memory span, leading him to postulate his magical number as a fixed limit on human performance.<sup>1</sup> According to Miller, access to a larger number of items could be generated by a mechanism called *chunking*, whereby several items already in long-term memory were given a single label that then served as a unique item. In suggesting this, he began the field of modern cognitive psychology by specifying its first internal, as opposed to environmental, cause of human behavior.

Most modern theories of memory trace their roots back from James (1890) and Hebb (1949), both of whom suggested that two different memory systems in the brain could be employed for immediate and long-term memory tasks, respectively. The most famous cognitive model of memory is the modal model that arose in the late 1960s. This model lays out many of the extant findings in an organized system that functions much like a computer (see Figure 1). One well-known formulation of this model is the Atkinson and Shiffrin (1968) version

<sup>1</sup>Miller's paper is often mistakenly thought to contain only his ideas on memory span, but his magical number applies to certain other limits as well.

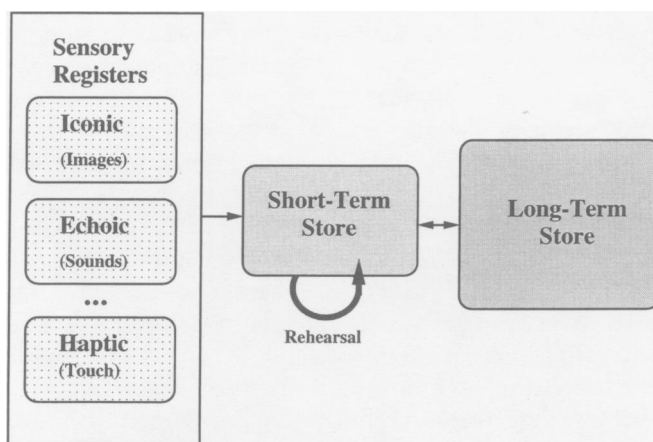


Fig. 1. Modal model of memory taught in many introductory psychology courses, based loosely on Atkinson and Shiffrin's (1968) model of memory. Information from the environment is stored in the sensory stores, which have unlimited capacity but very brief duration. Some of that information can be transferred to the short-term memory in the form of symbols (words, letters, digits, parts of images, etc.). Information can also be retrieved from memory traces in long-term memory and placed in short-term memory. However, only a very limited number of symbols can be maintained in short-term memory; if more items are stored there, then some will be forgotten. New information can be stored as a new memory trace in long-term memory if it can be associated with an existing trace in long-term memory – the latter is said to be a cue for the former.

(for recent behaviorally oriented reviews of this approach, see Catania, 1992; Donahoe & Palmer, 1994). In the modal model, information is first stored as a detailed sensory (e.g., visual, phonological, etc.) trace that lasts less than 1 s. Some information from this display can then be transferred to a limited-capacity short-term memory system that can maintain a few items as long as they are rehearsed or otherwise refreshed. If new items are to be stored in short-term memory, then the old ones will be forgotten. The long-term memory system functions associatively, with particular items being accessible because one item cues another. Items in long-term memory are stored semantically, that is, based on their meaning. To access items in long-term memory, they first have to be retrieved into short-term memory using these semantic cues. Items in short-term memory can then be changed and modified by "cognitive processes," or in other words, thinking.

Why did cognitive psychologists propose two separate memory systems? One key piece of evidence came from studies that investigated the kinds of errors made by participants in memory experiments. According to the modal model, recently presented items should be recalled from short-term memory, which stores items using a sensory trace (auditory, visual, etc.). If that were true, then recently presented words, for example, should be confused with similar sounding words (e.g., *tied* with *tide*) because they are stored as sensory memory traces. Items presented less recently should be stored using semantic memory traces, so that words with similar meanings should be confused (e.g., *tied* with *bound*). An oft-cited paper by Kintsch and Buschke (1969) addressed this issue in two studies. In each, participants read a list of words and then were tested with individual words from the list. Their task was to produce the following word from the list they had read. In the first study, the lists contained several pairs of semantically similar items, such as *angry* and *mad*. In the second study, the lists contained pairs of homonyms, such as *their* and *there*, which are acoustically similar. The results were consistent with the modal model. In the first study, more confusions occurred

with items from early in the list, whereas in the second study, more confusions occurred with items late in the list.

More recent cognitive models of memory have fractured short-term memory into several separate components that handle different types of information. This has happened because of data suggesting that new verbal information assumed to be in short-term memory does not disrupt memory for spatial information assumed to be in short-term memory except under extremely heavy memory loads and vice versa, whereas same-modality information does produce forgetting (see Baddeley, 1986, for a review).<sup>2</sup> Likewise, there is similar interference-based evidence that the short-term memory used to store information abstracted from sensory memory is not identical to that used to store either verbal or spatial information (see Pashler, in press, for a brief review).

The underlying constructs of long-term memory models are similar across many models and are generally based on interference (Anderson & Neely, 1996; Catania, 1992). Although some authors believe memory traces also decay, few dispute that interference exists (for reviews, see Catania, 1992; Cowan, 1995). The standard finding is that when items are similar, they tend to be harder to recall. When new items interfere with remembering of older items, it is called *retroactive interference*, and when previously learned items interfere with remembering of newly studied items, it is called *proactive interference*.

Critically, most processing is thought to occur in short-term memory because retrieval of items from and storage of items in long-term memory are supposed to require at least 2 s per item for most items (Chase & Simon, 1973). If less time were available, the items would be stored only in short-term memory, and would therefore be lost unless the participant actively rehearses them.

As we present our behavioral account of memory, we will argue that these cognitive models are unable to account for many of

<sup>2</sup>When the number of items exceeds about four or five, then there is some forgetting regardless of modality, but it is much greater for same-modality than for cross-modality information.

the findings at the expert level (Chase & Ericsson, 1981; Ericsson & Kintsch, 1995). Further, we will question whether they are even correct for nonexperts. In their place, we will propose an interpretation of memory based on observable behavior.

### IS BEHAVIOR INVOLVED IN REMEMBERING?

Although we support the distinction between long-term and short-term memory tasks, we see little reason to propose separate memory storage locations to explain them (Branch, 1977; Wixted, 1989). Instead, we agree with Catania (1992) and Wixted (1989), who suggested that a better distinction would be between short-term memory tasks in which some behavior such as rehearsal bridges the temporal gap between presentation and recall, and long-term memory tasks in which no such continuous behavior is present. The data supporting separate memory storage locations can be reinterpreted in terms of differences in stimulus control and type of response (Donahoe & Palmer, 1994; for a cognitive version of a similar argument, see Crowder, 1976, 1989).

Some cognitive phenomena are easily described in more familiar language. For example, proactive and retroactive interference between memory items are recognizable as response interference. When multiple responses are paired with the same stimulus, only the strongest response will be initially generated (Parsons, Taylor, & Joyce, 1981). If the responses are similar in strength, it may be impossible to produce either response (Keller & Schoenfeld, 1950). Other findings are less easily translated, and will require more understanding of the specific behavior engaged in by participants in the memory experiments.

Our account of these more complex memory phenomena is based on an elaborated form of Palmer's (1991; Donahoe & Palmer, 1994) interpretation of memory as behavior. We distinguish our analyses from his primarily by reviewing data from the cognitive literature that supports an extended version of his interpretation, as well as giving details about the complexity of memory performance among experts. We

can conveniently divide memory-related behavior into those behaviors that occur at the time or times of learning and those that occur during the actual recall of information. The former type of behavior we will call *acquisition strategies*, and the latter type of behavior we will call *remembering strategies*. We will suggest that these behaviors are acquired in response to standard selection pressures (i.e., reinforcement), and that they can be observed and therefore modified using currently available techniques – in particular, the “think-aloud” procedure described by Ericsson and Simon (1993).

The idea that remembering involves behavior that could in principle be observed and modified with the current technology is far from a foregone conclusion. For example, the behavior that facilitates acquisition and remembering could be highly overlearned to such a degree that it could not be inspected even by the individual engaging in the remembering, and produces no externally observable behavior other than the remembered response itself. In such a case, the mechanisms involved in remembering could at best be inferred from detailed studies of remembering behavior involving reaction times and accuracy. Alternatively, it is possible that all of the interesting behavior could be efficiently described only at the neural level, as some connectionist researchers have suggested, leading to fundamentally different requirements for observing and controlling the behavior. Finally, it might be the case that memory is based on universal memory abilities that apply to many different domains, as proposed by proponents of general intelligence theories, and that memory ability could therefore be fixed and unmodifiable even after specific training. Hence, a proposal that there is observable behavior involved is a relatively exciting one from a behavior-analytic perspective. Palmer's (1991) proposal is that some remembering involves simple stimulus control phenomena, in which a particular response is emitted in the presence of a set of discriminative stimuli. For example, children learn that the verbal stimulus *three times three* should produce the spoken response *nine* during calculation. Similar stimuli may

later elicit this same response through generalization. Sometimes, though, the correct response cannot be identified without additional behavior, which we will call remembering strategies (Donahoe & Palmer, 1994; Palmer, 1991; Skinner, 1953). Simply because the correct response is unknown does not mean that a person is unable to generate behavior related to the desired response. For example, when someone tries to remember the name of another person encountered at a social function, the situation may be aversive, with relief being obtainable only by generating an appropriate response. This may be accomplished simply by beginning to introduce the person whose name is unknown. In such a situation, the potential embarrassment of introducing someone and not knowing his or her name is sometimes enough to generate the correct response. The individual attempting to recall the information may try other strategies such as thinking of where they met the person in question and what subject was discussing during the meeting (Skinner, 1953). Strategies of this sort are examples of precurrent behavior and problem solving (Skinner, 1953, 1969). Current operant contingencies involve those effective responses that are likely to be reinforced, whereas precurrent operants are responses that increase the probability of future effective behavior. In the case of remembering strategies, the necessary responses are in the person's repertoire but cannot be generated without additional supplementary stimuli (Donahoe & Palmer, 1994).

What cognitive psychologists call *searching memory* frequently involves problem solving of this sort. For example, if I were to ask someone to recall the letter immediately before the letter J, most people would not be able to respond immediately. Instead, they would be forced to search memory – or, rather, to generate supplementary stimuli that would enable them to generate the correct answer. In this particular case, most people generate the letter H and then the letter I, allowing them to determine what the letter before J is (Klahr, Chase, & Lovelace, 1983). Such a strategy is not really “searching” anything, but is rather emitting a series of responses in the presence of particular discriminative stimuli or verbalizing an

intraverbal as a form of precurrent behavior (Skinner, 1957, 1969). Palmer gives an example drawn from everyday life rather than the memory experiment we have chosen; telling what you did on a particular day last week might involve figuring out what day today is, and how many days ago different events happened, such as taking a trip. He draws an analogy to playing 20 Questions, in which each response serves to further specify the correct answer. In short, the production of an answer in such memory searches is controlled by a sequence of additional stimuli that are generated during problem solving.

Palmer (1991) also describes acquisition strategies, which are precurrent behavior happening at the time of learning that serves to facilitate later remembering by increasing the probability of discriminating the correct response during remembering. Among the strategies he describes are grouping of stimuli, rehearsing, using imagery, and organizing material to be remembered (Donahoe & Palmer, 1994). However, the acquisition strategies described by Palmer are fairly rudimentary and do not involve the generation of additional responses on the part of the organism that then become part of the environment and therefore are able to serve as discriminative stimuli (Palmer, 1991). We will describe acquisition behaviors that Ericsson and his associates (Chase & Ericsson, 1981, 1982; Ericsson & Delaney, in press; Ericsson & Kintsch, 1995) have called *memory skills*, with which additional discriminative stimuli are in fact generated by the learner. Such skills turn out to be necessary for performing feats of exceptional working memory, such as those required to play a good game of chess (Ericsson & Kintsch, 1995).

Behavior analysts have scarcely begun to investigate the role that precurrent behavior plays in human functioning (Parsons et al., 1981). Parsons et al. explain that there are three ways that precurrent behavior can affect an operant. First, precurrent behavior can alter the probability that the organism will contact the discriminative events necessary for appropriate behavior to occur. An example used by Skinner (1953) was that a hungry individual may engage in behaviors

that bring him or her closer to a dinner plate, which then facilitates eating. A second type of precurrent behavior may alter the probability that future behavior will be reinforced. An example of this would be when individuals precede a particular response with autoclitic behavior (Skinner, 1957), thereby changing the probability of reinforcement for that particular response. Finally, precurrent behavior can serve to increase the likelihood that subsequent operants will "fall within the functional limits of the response class" (Parsons et al., 1981, p. 253). Acquisition strategies are often examples of this sort of precurrent behavior. For example, teaching participants to link words together using a narrative improves remembering by six to seven times compared to yoked (by study time) control subjects (Bower & Clark, 1969). Although each of the above functions of the precurrent behavior may serve to strengthen acquisition and remembering, it seems that the third type is most relevant for the current analysis.

One shortcoming of Palmer's (1991; Donahoe & Palmer, 1994) account is that much of the evidence provided for his view involves thought experiments rather than references to existing data. He also provides no systematic way of observing the usually covert acquisition and remembering behaviors and thereby studying and modifying them. To ameliorate this, we will draw upon the extensive cognitive literature on memory, particularly work that has appeared within the last quarter century on experts that may not be familiar to many behavior analysts. However, most cognitive experiments provide insufficient data to evaluate claims about acquisition and remembering behavior, focusing as they do on testing the plausibility of various hypothetical constructs.

### THE NECESSITY OF USING RICH INDIVIDUAL-PARTICIPANT DATA

Much of the important behavior that occurs in a standard cognitive psychology experiment happens very rapidly and covertly. Therefore, the standard laboratory paradigm has been tailored to try to infer the behavior the participants are engaging in. In memory

research, this typically involves repeatedly measuring reaction times and some form of accuracy data for a group of participants and then statistically comparing them with another group of participants that either differs on some measurable dimension or that performs a different task. The rationale for studying reaction time is that, as a popular cognitive textbook puts it, "mental events take time" (Ashcraft, 1989, p. 33). Of course, most behaviorists would not use the term *mental events*, but the statement is equally accurate if one rephrases it as "behavior, both overt and covert, takes time." Theoretically, two groups that differ in total reaction time on the same task must be doing something different or have different abilities. Often, experiments are arranged so that the pattern of observed reaction times for different stimuli within the experiment can be used to differentiate between rival descriptions of the processes necessary to complete the task.

The main difficulty with using reaction times alone is that they do not usually uniquely specify what behavior the participant is engaging in while performing the task. Individual participants may be performing the task using methods that differ from those used by the majority of participants (Ritter & Bibby, 1997; Siegler, 1987), and aggregating data over participants can produce average models that fit the group well but do not fit any particular individual at all (Delaney, Reder, Ritter, & Staszewski, 1998; Siegler, 1987; Walker & Catrambone, 1993). Other kinds of data, such as accuracy or recording of overt behavior, are similarly insufficient for the study of covert behavior. A few methods, such as the relatively new eye-tracking methods, are useful for studying perceptual behavior, but they still yield little new information about the covert behavior invoked during thinking.

The best available methods for studying covert behavior involve the use of verbal protocols (Austin & Delaney, 1998; Ericsson & Simon, 1993; Hayes, 1986; Hayes, White, & Bissett, 1998). In particular, we recommend the use of the method of thinking aloud, which involves nonintrusive instructions to verbalize thoughts as they occur, and so provides a way of making covert behavior

overt. We note that this is not the same as introspection, because participants are not asked to comment on their thoughts or to describe what they must have been thinking. Introspective methods, particularly when applied retrospectively, often lead to inaccurate descriptions of behavior (Ericsson & Simon, 1993; Nisbett & Wilson, 1977). As long as standard instructions are used, thinking aloud does not appear to alter the form of the covert behavior significantly, or at least does not affect accuracy.

Whereas protocol analysis has a long and distinguished tradition in problem solving (e.g., de Groot, 1946/1978; Newell & Simon, 1972), it has not frequently been used in the study of memory, because memory was thought to be mediated by hypothetical constructs rather than by behavior (Ericsson & Delaney, *in press*). Because researchers did not expect to find any behavior that affected memory, other than perhaps rehearsal techniques, such behavior has been obscured in laboratory studies of memory.

In the next section, we will discuss some of the growing evidence that memory relies on both acquisition and remembering strategies. In doing so, we will also explicate some of the implications of this view for the understanding of skilled and expert performance.

### EVIDENCE FOR ACQUISITION AND REMEMBERING STRATEGIES

In this section, we directly address the evidence for our interpretation of memory as behavior. Although we cannot in this paper rule out the possibility that hypothetical constructs such as short-term memory are necessary to explain remembering behavior, we will demonstrate that an understanding of the behavior that occurs during acquisition and remembering is necessary to explain some data that otherwise are difficult for modern cognitive theories to address. In particular, our review is closely based on that of Ericsson and Kintsch (1995) and Ericsson and Delaney (*in press*), who argued that the way experts meet the memory demands placed on them can only be explained by reference to what they called *skills* and what we will describe as behaviors. These earlier proposals were primarily

aimed at explaining *working memory*, which is the name given to phenomena involved in stimulus control by perceptually unavailable stimuli over relatively short time periods. We will also discuss generalized remembering from this perspective, because we believe the mechanisms involved are very similar.

Expert performance is a fertile ground for the study of many important phenomena, including remembering, because theoretically an expert is a person who has become maximally adapted to his or her task domain (for an excellent review of maximal adaptation in various task domains, see Ericsson & Lehmann, 1996). To become an expert, one needs to perform the defining tasks of the domain better than virtually anyone alive; for example, Ericsson and Charness (1994) propose that an expert must consistently perform at a level at least two standard deviations above the population mean on relevant tasks. Hence, one would expect to see the greatest demands being placed on the memory system and the most advanced methods for dealing with human limitations in cases of expert memory (Ericsson & Kintsch, 1995). Although behavior analysts are probably most interested in improving the memory performance of relatively ordinary individuals such as schoolchildren and older adults (cf. Donahoe & Palmer, 1994), perhaps the way to get better at remembering is to study how the best memorists do it.

In the following sections, we will review some of the evidence from expert and novice performance for the use of acquisition strategies, remembering strategies, and problem solving during both acquisition and remembering. Then, we will argue that the available data are consistent with the claim that similar behaviors facilitate memory in all tasks, including unfamiliar ones.

#### *Rehearsal as a Strategy for Remembering Unfamiliar Information*

Verbal responses do not seem to be available for conditioning for more than about 2 s when behavioral strategies for remembering are eliminated, although why this is the case is unclear (Nairne, 1996, pp. 108-110; Baddeley, Thomson, & Buchanan, 1975). The 2-s limit is often proposed as an internal cause of the short-term memory limits

described in the introduction (e.g., Baddeley, 1986), although such an explanation would not be acceptable to behavior analysts because of the implied circularity of reasoning. Regardless of the source of this apparent limit, it raises the question of how untrained individuals maintain stimuli for conditioning over relatively short periods of time.

Nonexperts frequently resort to rehearsal (Catania, 1992; Donahoe & Palmer, 1994; Nairne, 1996). Topographically, rehearsal appears to involve a repeated covert echoic response to each presented word.<sup>3</sup> A plausible interpretation of rehearsal in behavioral terms has been provided by Donahoe and Palmer (1994). They believe that each item serves as a discriminative stimulus for the next item in the sequence by manufacturing intraverbal responses between the items. Consistent with this acquisition strategy view of rehearsal, rehearsing seems to be learned to meet the demands of the modern environment. We frequently need to remember seemingly unrelated items for short periods, such as telephone numbers, lists of items to recover from the pantry, and so on. When rehearsal is successful at maintaining information over short pauses, the precurent behavior supporting rehearsal is reinforced. In cultures in which short-term verbal memory is given less emphasis, such as among Australian aboriginals, children perform more poorly on span tasks than do comparable Australian children of European descent or aboriginals educated in western-style schools (Kearins, 1981).

Rehearsal cannot function indefinitely, however, chaining intraverbals together like boxcars. The 2-s limit is operative even when rehearsal occurs; without refreshing each link, the items are forgotten (Baddeley et al., 1975). However, these limitations have been overcome by some memory experts. In the next section, we will describe their methods.

#### *Evidence for Acquisition and Remembering Strategies from the Study of Memory Experts*

The earliest evidence that behavioral strategies could be used to improve memory came from the study of mnemonics, which

are simple behavioral techniques that either organize information or provide additional memorable discriminative stimuli that will be emitted with high probability during recall (for reviews, see Bellezza, 1981, 1996; Catania, 1992). The oldest such techniques have been in use since at least Roman times, when they were taught as part of rhetoric (Yates, 1966). The classic mnemonic device is the method of loci, which is useful for learning lists. In it, the memorist learns a set of locations extremely well, usually based on a place he or she has actually been, and then systematically rehearses the list in pairs with the various locations. Typically, the instruction is to visualize items from the list at each location rather than just verbally repeating them. For example, if a politician wished to remember the order of some laws to be brought up at the city council meeting, he or she could begin by associating images related to the laws with locations in his or her home ("dining room – toy cars [for the new road repair bill], kitchen – hard hat [for the construction tax], hall closet – ping pong table [for the new park hours] ..."). The politician would then rehearse the list until it could be repeated verbatim many times. The mnemonic is effective because at the time of recall the well-known list of places can be produced without difficulty. Because of the earlier rehearsal, each location serves as a unique discriminative stimulus for the relevant item. The item in turn, together with contextual cues such as "standing in the city council chambers with everyone looking on" serve to occasion the response of talking about the appropriate law.

The method of loci and related mnemonics require extensive rehearsal and therefore a great deal of time. Chase and Ericsson (1981, 1982), however, have shown that acquisition and remembering behavior can be used to recall even rapidly presented items. They became interested in whether Miller's (1956) famous proposed capacity limit on short-term storage of  $7 \pm 2$  items could be surpassed given sufficient practice at memorizing digits. One stable demonstration of capacity limits comes from span tasks like the digit span or word span tasks, which have been used to evaluate the durability of verbal responses since the early days of IQ

<sup>3</sup>At least in humans. We know of no way to observe rehearsal in nonhumans (Wixted, 1989).

testing. In this task, digits, words, or other verbal materials are presented sequentially at the rapid rate of one per second. Immediately after the end of each list, the participant is asked to reproduce the list verbally in the same order. If successful, the length of the next list is increased by one; if unsuccessful, it is decreased by one. The participant's span is the list length that can be correctly reproduced 50% of the time.

Chase and Ericsson (1981, 1982) exposed their participants to repeated trials on the digit span task. Although the participants were given no explicit instruction in memorizing, all 4 of them achieved a digit span of 20 or more digits after only 50 hr of practice, and 2 participants, SF and DD, eventually reached spans of over 80 digits following several hundred hours of practice (Chase & Ericsson, 1982; Staszewski, 1988a). Reinforcement in the task was not recorded by the experimenters, but comparison with similar experiments (e.g., Ericsson, Delaney, Weaver, & Mahadevan, 1996) suggests that these participants were selectively praised for successfully remembering the digit lists. Further, even if praise was not delivered, it is likely that correct responses reduced the aversive condition of not knowing the answer. Hence, their performance would need to continue to improve in order to receive reinforcement.

To assess their methods, the participants were asked to provide retrospective reports on their covert verbal behavior during the memory trials. The participants were asked to remember the behavior they engaged in, but not to guess at what they must have thought or to comment on it. For the first few sessions the participants reported using rehearsal techniques similar to those used

by most untrained participants on the digit span task (see our earlier discussion of rehearsal above). Because rehearsal techniques fail for longer lists, the participants needed to use new acquisition strategies that were revealed by the verbal reports. The new strategies involved generating additional grouping stimuli that could then be recalled at a later time. For example, "408" could be related to the time to run a mile by thinking of it as "8 seconds away from a 4-minute mile" (Ericsson & Delaney, *in press*). When asked to remember the list, the participant would then produce this intermediate stimulus in response to the question, and then use it to reconstruct the original digits. The method improves performance because trying to recall the digits alone produces substantial proactive (i.e., response) interference. On the other hand, "mile time" is a relatively unique item that can serve as an effective discriminative stimulus for the particular response. This requires that the approximate time to run a mile be in the participant's repertoire, and therefore depends on prior experience. By using standard labels, such as labels based on running times or ages, the participants were able to capitalize on their knowledge of their own encoding methods to more effectively occasion the proper label as well. It is important to realize that the digits were not simply recognized as a familiar response; it is unlikely that the response "8 seconds away from a 4-minute mile" would normally be generated directly from the digits 408. However, SF and the other participants learned to produce such responses through problem solving because they were effective during remembering.

Eventually this method too proved to be insufficient to receive further reinforcement.

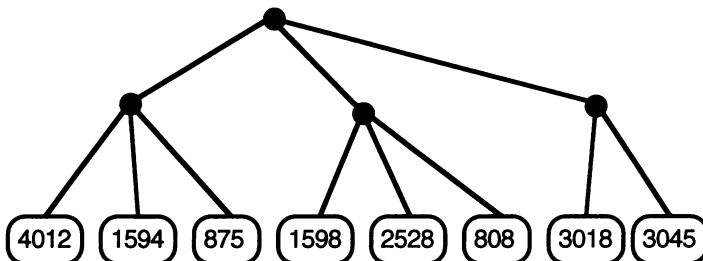


Fig. 2. Diagram of a retrieval structure similar to one reportedly used by the digit span expert SF (Chase & Ericsson, 1981). The retrieval structure consists of two supergroups, each of which consists of several mnemonically grouped sets of digits. To remember a digit, SF remembers which supergroup it is in, then remembers the appropriate group, and then the appropriate mnemonics, and finally the requested digit.

At this time, SF and DD learned to handle multiple such groups by assigning them a spatial position (e.g., the left one, the middle one, the right one). Later, they even used "retrieval structures" consisting of hierarchical layers of groups of groups (see Figure 2). They imagined the structure shown in the figure, tailored to the specific list length they were to recall. When the trial began, they began as before, generating associations such as those described above for the first few digits. These associations were generated "on the fly" as they heard the digits. Once two or three of these labels had been generated, the participants rehearsed the group labels quickly as a "supergroup." They then started a new supergroup of two or three labeled groups of digits. The process was then repeated for each successive supergroup. At recall time, the participants would take each supergroup in order and first recall the two or three labels from that group. Then, each label would be used to reproduce the digits it stood for. Consistent with the view that each level of the hierarchy was remembered and was then used as a discriminative stimulus to recall digits within the group, the time required to remember the first digit in a group was much longer than the time required to remember additional digits, given that the first had been recalled correctly (Ericsson, Chase, & Faloon, 1980; Staszewski, 1988a). Likewise, once multilevel structures like that in Figure 2 came into use, it took longer to retrieve digits that required retrieving a different supergroup than it did to retrieve those in the same supergroup.

The reason the retrieval structures were effective is that they provided a method for overcoming proactive interference. By including the additional discriminative stimuli of spatial position and the semantically related labels, the participants were able to produce relatively unique pairings of stimuli and responses, reducing the response interference dramatically.

The digits and associated responses supporting their recall could still be reproduced long after they had been acquired, unlike digits acquired using simple rehearsal techniques. Chase and Ericsson (1982) found that following a session, SF was able to correctly remember more than 90% of the presented

digits. In addition, their participants frequently recognized the relationship between digit groups that started with the same pair of digits as earlier digit groups, even across sessions. Taken together, these findings suggest a remarkable resistance to response interference brought on by the use of the supplementary stimuli during acquisition and remembering.

In conclusion, the supplementary stimuli generated during acquisition served two purposes in this task. First, they were high-probability responses given the context during remembering, because they were sufficiently distinct from other responses so as to produce more effective discrimination. We will argue in a later section that this often means that they are semantically appropriate for the domain in which they are being used. The result is that the lower probability response is more easily acquired because it can be remembered using the newly generated high-probability response as a discriminative stimulus. Second, the supplementary stimuli can preserve the conditioned response by preventing extinction due to competing responses being conditioned to the same stimulus.

Finally, cognitive models that view remembering as a function performed by memory stores have trouble explaining these results. These semantic relationships should not be possible to acquire if most processing really takes place in a separate short-term memory that requires 2 s per item to store. Chase and Ericsson's (1981, 1982) participants needed much less time to learn the desired responses once the relevant precurent behavior was acquired. In contrast, a behavioral account has no difficulty explaining these results.

#### *Evidence for Acquisition and Remembering Strategies from Laboratory Learning Tasks*

There is good evidence that even novice participants can use acquisition strategies to improve their memory performance on tests of memory for meaningless materials such as nonsense syllables. As early as 1918, Reed reported that participants used "associative devices" such as similar sounds and making sentences out of presented words to facilitate

remembering of otherwise unrelated words, but these were deemed to be irrelevant to the study of the memory trace.

More recent work has solidified the argument that *natural language mediators*, which are acquisition strategies involving verbal behavior, are extremely important in remembering otherwise unrelated material. For example, Kiess and Montague (1965) tracked the frequency of use of such natural language mediators in a list-learning task. Each stimulus list consisted of eight nonsense syllable-English word pairs (e.g., TOZ-cloth) presented for 5 s per pair. The procedure involved three phases. First, the list was presented. Then, participants were shown each of the nonsense syllables for 5 s and were asked to remember the corresponding word. Finally, they were asked to do this second task again, but this time they gave a retrospective report. This same procedure was repeated eight times with the same list. The main result was that the use of natural language mediators steadily increased over the course of the experiment, as did memory for the list items. When a second group of participants was presented with eight different lists instead of the same list eight times, participants recalled less than 30% of the items from the lists, a number that corresponds closely to the percentage of trials on which natural language mediators were reported (about 20%). Other studies later confirmed that using these acquisition strategies greatly enhanced the likelihood of remembering particular items (48% vs. 20%), and that the probability of correctly remembering was very high (97%) when participants could verbalize the natural language mediator (for a review, see Montague, 1972).

There are similar results on what we will call *conditioned perceptual mediators*, which are imagery-based acquisition strategies. For example, Wallander and Elliott (1997) performed a study linking improvements in performance on a memory task to the introduction of a verbal naming strategy for memorizing unfamiliar symbols (Japanese kanji and katekana). The strategy involved associating the unfamiliar symbols with familiar images. For example, 1 participant associated a katekana symbol with the word *turtle* because of the symbol's shape. During

recall, the participant was observed to first verbalize the name of the perceptual mediator (*turtle*) and only then to select the proper response from the display. Wallander and Elliott found that only after participants adopted this sort of strategy did their performance improve, and once the strategy came into use it quickly became the dominant strategy and performance on the task hit ceiling. Closely related research from the cognitive literature has been reviewed elsewhere (Montague, 1972; Paivio, 1979). Some of the most compelling evidence for the use of conditioned perceptual mediators comes from research showing that congenitally blind participants, who do not have conditioned perceptual responses in their repertoire, are unable to make use of imagery techniques to improve their performance on list-learning tasks (e.g., Paivio & Okovita, 1971). Likewise, the conditioned perceptual mediators can be interfered with by presenting visual stimulation externally, whereas natural language mediators are relatively unaffected by visual stimulation (see Paivio, 1979, for a review). Although to our knowledge the reverse study has not been done (attempting to interfere with production of natural language mediators by presenting unattended speech), there is a large body of research showing that other verbal behavior can be interfered with using such methods (see Baddeley, 1986, for a review).

Studies that directly address the issue of problem solving during remembering or the use of remembering strategies other than those naturally employed as a consequence of having used particular acquisition strategies at an earlier time are rare. However, it is clear that at least expert memorists do make use of various remembering strategies like those proposed by Palmer (1991). Some behavior analysts have also noted the use of mediating verbal behavior in experimental tasks (Potter, Huber, & Michael, 1997; Wulfert, Dougher, & Greenway, 1991). In general, these remembering strategies include the use of problem-solving techniques to generate additional likely stimuli that might serve as useful discriminative stimuli. For example, the memorist Rajan is able to memorize lists of 75 digits presented at a rate of one digit per second in groups of 10 digits

at a time (Ericsson et al., 1996). When he couldn't correctly produce a digit group during remembering, he sometimes produced a sequence of possible initial digits in order (0 to 9, or even 00 to 99) trying to find one that would serve as an effective discriminative stimulus for selecting the correct digit group. Similarly, Ericsson and Chase (1982) found that SF, when asked to remember what digit group ended with a particular three digits, say \_032, he would frequently have to try each digit from 0 to 9 in the first spot until he generated a group that he recognized. In these cases, the correct response is unknown until it is emitted (Skinner, 1953). The technique is used to facilitate remembering when the original supplementary stimuli fail to elicit the required response, or when they are unavailable.

It is natural to ask whether these complex acquisition and remembering strategies are used in everyday memory, or whether they are restricted to artificial situations in which large amounts of unrelated material need to be reproduced. In the next two sections, we will document evidence that remembering and acquisition strategies are a necessary and integrated part of the behavior that mediates expert performance. In particular, we will argue that acquisition and remembering behaviors emerge as a natural consequence of the selection pressures enforced by the tasks that experts engage in.

#### *Behavioral Strategies Used During Learning and Remembering in Naturalistic Task Environments*

Despite the obvious interest one would expect in studies on remembering in applied contexts, there has been surprisingly little empirical work to date addressing the specific question of whether or not acquisition and remembering strategies are used in naturalistic contexts. One exception is the development of verbal rehearsal techniques, which have been studied extensively (for a very brief review of relevant research, see Siegler, 1991, pp. 183-185). As another example, some work uses externalized aids in conjunction with various remembering strategies. For example, "memory wallets" have been used to improve the factual content of conversation for older adults with

dementia (e.g., Bourgeois, 1992). The approach used a wallet with pictures and sentences about 30 things that participants had trouble remembering. All 9 participants' conversational factual content improved, and 3 participants' improvements were maintained at a 30-month follow-up.

The problem, however, of identifying everyday memory strategies and observing them in the laboratory is that the kinds of situations that elicit remembering behavior in everyday functioning are not always easily defined or replicated in the laboratory. Consequently, there is a paucity of research addressing the use of acquisition and remembering strategies in everyday memory. Even among experts, for whom the task demands are more easily identified, much of the evidence for behavioral facilitation of memory phenomena must be indirect because the relevant behavior occurs rapidly and covertly. Even using protocol analytic techniques, acquisition strategies may be difficult to observe directly, because experts are so highly skilled that the strategies may be applied within a few seconds. However, we can make some educated guesses about what such strategies must look like if they were to be directly observed based on evidence about what experts can and cannot do.

Expert behavior has been selected over many years of practice, and there is ample evidence that the physical and behavioral characteristics of experts are maximally adapted to meet the demands of the task (see Ericsson & Lehmann, 1996). There is no a priori reason to assume that acquisition and remembering strategies, if employed at all, would not be similarly adapted to the specific demands of the task (Ericsson & Kintsch, 1995). We would not expect that behavior facilitative of remembering irrelevant information would be reinforced; so, if it is possible to statistically predict what information is likely to be useful, then the expert can acquire a repertoire including acquisition and remembering behavior that supports performance on the task. Therefore, if we observe remarkable memory performance among a group of experts, we would generally assume that the remarkable memory performance is functional. Mere exposure to a domain does not generate the

ability to memorize large quantities of information rapidly; expert mental calculators and mental abacus calculators, for example, have exceptional memory for digits, but not beyond what is necessary to perform their feats of exceptional calculation (Ericsson, 1985; Staszewski, 1988b). Therefore, we could speculate that expert chess players' ability to memorize entire chess boards rapidly (de Groot, 1946/1978) and to reproduce them even after performing other difficult tasks (Charness, 1976; Frey & Adelman, 1976) indicates that this ability is important for effective chess play. Perhaps the strongest support for such a claim comes from studies showing that chess players show exceptional memory for chess positions only when asked to perform chess-relevant tasks using the boards. For example, chess masters can recall the boards well when asked to decide whether a king is in check but not when they are merely asked to count the pieces on the board (Saariluoma, 1985).

Why would expert chess players need to remember whole chess positions? In many expert tasks, including chess, the problem is not simply one of remembering presented information, but rather of transforming that information in some way. For example, during planning in chess one has to produce long chains of responses to evaluate particular moves. That means that the problem is not simply one of remembering all of the information that has been presented but rather of selectively remembering only the information that is called for by the current context. Hence, the problem is one of bringing large numbers of responses rapidly under stimulus control when the stimuli that will be used to elicit the response are not currently known. In the case of chess, it is relatively trivial and ineffective to teach a participant to remember all the pieces on a chess board; 1 participant was able to learn to do this using conditioned perceptual and natural language mediators in under 50 hr of practice (Ericsson & Harris, 1990). This turns out to be useless for playing actual chess because evaluating whether pieces were attacking or defending one another would require sequentially producing each of the pieces and their locations in turn, and

then laboriously checking whether an attack-defense relationship existed between them (Ericsson & Delaney, in press). Chess masters are able to notice such relationships almost immediately, which requires that the locations of pieces be under the control of game-relevant stimuli, such as "the knight is on the same row as the rook" – an attack relationship between knight and rook. In support of the claim that the ability to memorize chess positions depends crucially on acquisition strategies, studies of masters attempting to memorize briefly presented random chess positions – positions that could not occur in a real chess game – find that the masters are only slightly better at reproducing these boards than untrained players are (Gobet & Simon, 1996). In such cases, the masters could not rely on the usual acquisition strategies involving attack-defense relations, because these relations did not make sense in terms of the chess positions.<sup>4</sup>

### CONCLUSIONS: CAN WE IMPROVE MEMORY PERFORMANCE?

In this paper, we have used the term *memory* rather loosely in referring to what cognitive psychologists describe as higher mental processes and behavior analysts describe as responding under stimulus control. At the outset, we argued that memory phenomena could in principle involve very little observable behavior. Under such conditions, it would be difficult to improve memory performance in ordinary people because it is not clear what behavior would need to be changed – perhaps we could teach the use of "external" memory in the form of lists or reminders. In such a case, we would at best be able to observe limits on higher mental processes and roughly describe them, without being able to exert control through the usual conditioning mechanisms. It is not until higher mental processes are conceptualized in terms of acquisition and remembering repertoires that it becomes clear that

<sup>4</sup>The situation turns out to be a bit more complex than this, and with time chess masters can reproduce even random positions (Saariluoma, 1989). For a more detailed discussion of the involvement of acquisition strategies in chess, see Ericsson and Delaney (in press).

many limits on performance, especially those involved in temporary maintenance of information (working memory), can be understood as behavior and therefore can be changed.

Our review suggests that a behavioral interpretation of memory-related phenomena could benefit from inspecting, at the level of the data (Skinner, 1950), some of the findings of cognitive psychology. A similar conclusion has been reached in excellent books by Donahoe and Palmer (1994) and Catania (1992). Such inspection could lead to determination of the behaviors that occur during acquisition and remembering and that facilitate appropriate responding in recall situations. A better understanding of these behaviors could then lead to our improving their functional control over novice performance in a variety of domains. One direction this approach could take would be to use the "silent dog" set of controls proposed by Hayes et al. (1998) to verify antecedent verbal stimuli used by experts and then to train novices to use them for the purpose of improving their performance in the domain. A variation on this approach, called "think aloud problem solving" (Whimbey, 1995), has been used in applied settings such as the Morningside Academy (cited in Lindsley, 1996).

We have focused on how experts acquire skills and remember, and our tentative conclusion is that acquisition and remembering strategies like those described by Palmer (1991; Donahoe & Palmer, 1994) and Ericsson and Kintsch (1995) are involved in effective performance in many domains. Our hope is that the repertoires that are facilitative of performance in a variety of applied domains can be studied using protocol analysis and other repertoire-mapping techniques (cf. Austin & Delaney, 1998; Hayes, 1986; Hayes et al., 1998), and that the acquisition and remembering strategies underlying performance on these tasks can be observed and modified to achieve socially important ends.

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